Controlled Velocity Testing of a Micro Wind Turbine with Varying Blade Geometries

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***Abstract*—Micro wind turbines are being used with some success at remote hilltop communication stations in Labrador. It is observed that wind generation at these sites reduces diesel consumption and increases battery life; however, these benefits are offset by the installation costs and servicing of the multi-unit micro WEC systems. One of the primary maintenance issues is the occasional catastrophic failure of one or more of the wind turbines during severe weather. It is acknowledged that the conditions imposed on these commercial units reaches beyond the intended operating range specified by the manufacturer. This paper describes an experimental program aimed at improving the harsh climate resilience of the standard WEC units. Specifically, blade variations are to be tested in controlled velocity tests in which a vehicle mounted test platform equipped with turbine control and DA electronics will be utilized.**

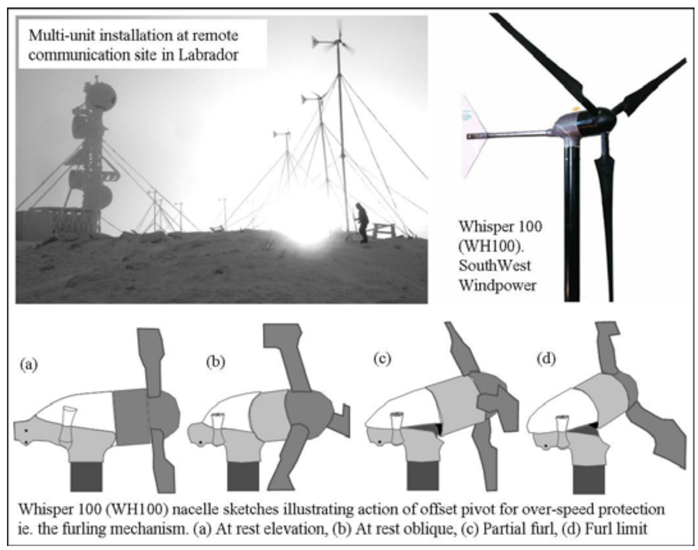
***Index Terms*— Micro, Wind, Turbine, Extreme, Environments**

I. Introduction

THIS work investigates the modification of commercially available mass-produced micro wind turbines. The specific unit tested, SouthWest Windpower's Whisper 100 (900 Watts, 2.1m diameter), matches the brand and model of the units investigated in earlier work by the authors [1][2]. In that work it was determined that catastrophic failure of units occurred under extreme wind conditions beyond the intended operating range specified by the manufacturer (survival speed specified at 55 m/s while winds repeatedly exceeded this). Remarkably, many units did survive at sites where these and slightly less severe conditions prevailed.

The primary mode of failure was the complete parting of nacelle body via a diagonal crack across the cast aluminum housing. Though none of the events were directly observed it has been concluded that rupture resulted from furling-induced impact stresses or more specifically, the overloading of the nacelle body casting due to the action of the furl-brake system (Roberts and Bruneau 2008). The over speed protection system for the WH100 utilizes an off-vertical pivot separating the tail/yaw body section from the blade/hub body section (Figure 1). When wind loads on the operating hub are sufficiently high, that section of the turbine rotates around an inclined plane away from the wind direction – the returning force being that of gravity for the elevated part. It appears that rapid furling from excessive gusting induces extreme flexural stresses across the body of the nacelle due to the position of the internal casting/rubber brake pad relative to the furl pivot and rotor shaft (the point of concentrated wind load). This brake/stop element is located between the spinning rotor and the furl pivot so that impact and quasi-steady loads on the nacelle body are exacerbated by mechanical leverage – ultimately resulting in brittle failure across the body section of least resistance.

Figure 1 Whisper 100 micro wind turbine



It may also be pointed out that the action of furling is highly complex for several reasons and can, therefore, not be easily predicted. Of course the precise fluid dynamics of air flow through and around the turbine at various furl angles is itself an intractable calculation; however, it is the action of angular momentum combined with machine asymmetry that completes the challenge. Figure 2 illustrates the tendency for a clockwise rotating rotor to furl via the action of rapid yaw-induced rotation of the nacelle alone. Similarly, yaw rotations in the opposite direction may cause either rapid unfurling, or, delay the onset of furling from normal position. Additionally, the position, velocity and acceleration of the tail vane is not a function of uninterrupted wind dynamics alone – these quantities are also influenced by furl-induced mechanical

Manuscript received October 9, 2008. This work was supported in part by Bell Aliant, St. John's and Memorial University of Newfoundland.

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torque and wind patterns around the asymmetric machine.

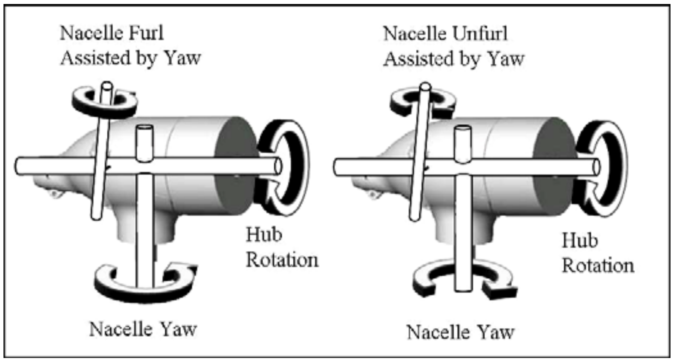

Figure 2 Conservation of angular momentum implications.

The manufacturer indicates that over speed protection is the intended purpose of the furling mechanism [3], however, in the severe conditions described herein, the furling action leads to complete unit loss and thus provides no value in its present form as a sacrificial feature. It is not known what the failure mechanism would be in these units if the furling feature were absent altogether, nor is it known for how long or to what extent the furling action postponed unit failure thus extending operational life. Thus it can not be concluded that furling is unequivocally detrimental to unit performance, nor that it is always a benefit. Indications are that barring collateral damage, the only failure mechanism more costly to repair than nacelle structural failure would be failure of the support tower structure. If the tower integrity was lost, perhaps via anchor pullout, civil repairs would be time consuming and costly, in addition to the inevitable damage to the turbine.

II. EXPERIMENTAL PROGRAM

A. Concept

An experimental program has been designed to examine the performance characteristics of the Whisper 100 unit, and variations, under controlled velocity conditions. The productivity and furling behavior of the standard unit in the quasi-steady air speeds and gust-simulated conditions of the controlled program will be measured. With these qualities known it is proposed to repeat the trials with the unit outfitted with modified blades which effectively reduce swept area – a sacrifice which may enhance survivability and hence economics in severe climatic conditions. It is of interest to the authors to know the extent of the power/performance delta resulting from this modification plus the associated change in furl behavior and resulting unit stresses. It may be of interest to note that in practice the implementation of these modifications may only be seasonal as it is the goal of the authors to determine the optimal load-reducing and resilience-enhancing modification *and* practice. The suppression of the mechanical furling feature - in combination with the aforementioned blade size modifications will also be tested. It is an assertion here that at some point in the blade/area reduction experiment it is probable that the furling action ceases to be an asset and becomes a liability mechanically and/or structurally.

Wind tunnel testing was not possible locally as the turbine dimensions exceeded the cross section of the largest wind tunnel available, and other methods of creating wind for controlled velocity testing on a stationary unit were not within budget constraints. Therefore, a vehicle/trailer mounted system is proposed whereby all equipment and electronics is to be mounted on a mobile platform and translated along a straight roadway under favorable conditions - thus creating the relative affect of controlled wind speed. Using anemometers, airspeed will be closely monitored in real time and thereby regulated with vehicular control. Though imperfect, this approach offers significant time and cost benefits over conventional ambient wind testing on stationary turbines.

B. Location

Two locations have been identified for field testing, the first being a remote public roadway with extended straight sections through relatively flat grassy terrain with few obstructions, no bridges or overhead wires (Witless Bay Line). It is proposed that RCMP notification of ongoing work will be sufficient to legitimately carry out the planned tests. The second, a backup location, is a local abandoned airstrip typically used by model aircraft hobbyists. The shortcoming of the latter option being the relatively short length of the runway and the long (1.5 hr) travel time from the University.

C. Equipment

A 7m long, 1.5m wide, dual axle ATV trailer has been identified as the preferred test platform due to its excellent tracking characteristics, large load capacity, spacious surface area, its ease of mobility, and, its availability. It is proposed that the turbine be rear-mounted on a pole extending above the airflow influence of the towing vehicle whilst being capable of lowering and being secured easily for work or stowage during transport. The anemometers would be similarly mounted at least 2 diameters (4.2m) forward of the turbine. Cameras, laptops, control modules, displays are all to be mounted on the trailer with most items secured in an easily accessible weatherproof box. An auxiliary AC power supply on the trailer will be used if required. A sketch of the proposed scheme is provided below in Figure 3.

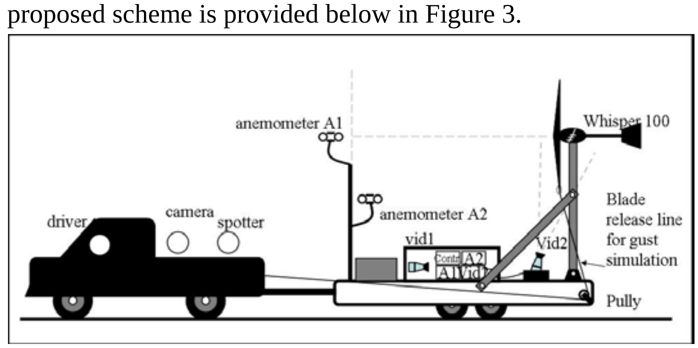

Figure 3 Proposed Experimental Set Up

Typical of field work, data acquisition, data handling and data processing are key to experimental success. Experience suggests simple and robust systems provide clean, manageable results for first-order observations and conclusions, sacrificed is the ability to see or quantify higher order affects and subtleties otherwise captured in sophisticated systems. Given the fundamental nature of the proposed apparatus modifications and likely results, the authors have elected to limit the complexity of the DA system. It is proposed that a simultaneous video recording of the turbine output display, airspeed display and auxiliary camera display(s) (showing unit operation and furling with marked gradations) provide the primary data record. In this way all key information is recorded on one analog or digital video record. Additional camera records will also be taken to provide additional experimental records and backup. At least three persons are required for the safe conduct of the tests – a driver, a spotter and a camera person.

Image resolution and video sampling rate will dictate the manner in which the DA this system is assembled and viewed. Post-processing will require manual analysis of the video record so that power, rpm, voltage, amperage, airspeed and furl angle can be transcribed for discrete time intervals for each trial. The readout flutter and shift resulting from rapid changes in ambient conditions or display characteristics will need to be assessed before deciding how many "data points" are required to establish a mean performance characteristic for each of the quasi-steady state airspeed conditions tested.

III. Test Procedure

A. Experimental Range

Table 1 lists the proposed sequencing of tests. The airspeed range may be adjusted in the field as experimental confidence is gained. The range of speeds shown (0-20 m/s) covers the apparent zero-to-maximum furl action (0 – 63 degrees) observed by others, including Davis *et al.* [4] as reproduced in Figure 4.

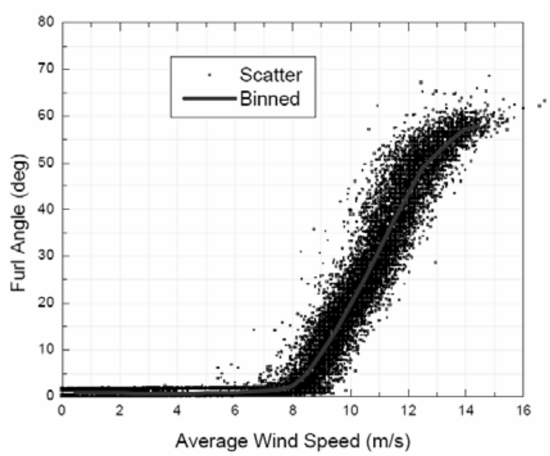

Figure 4 Furl Angle Versus Wind Speed from Davis and Hansen, Windward Engineering L.L.C. July 2000

The blade lengths selected are based on the calculated assumption that load reduction will be proportional to swept area reduction so that approx 1/10th and 1/3rd area reduction will result from 5cm and 20cm blade tip removal. It is further assumed that start-up speed will not be significantly raised by these changes due to the likely near-rotor dominance of blade lift at low speeds – an artifact of specialized blade airfoil geometries with outward tapering pitch and chord length. For these experiments it is also assumed that if production were curtailed by more than 33% the *potential* improvement in survival would not be justified. This assumption may be tested posterior once results from this work are known and future work extending the range or nature or improvisations are made.

B. Experimental Procedure

Selecting an inactive weather window will be important for control, quality and comfort. Essentially, no precipitation and light to no winds are preferred. Setting one week aside for testing in the early fall in the St. John's area would likely provide at least one day for testing with some degree of certainty. Days prior to heading out into the field a full function rehearsal of the logging procedure will be undertaken for troubleshooting and debugging. This can be carried out by translating the trailer the length of the parking lot adjacent to the university laboratory workshop.

Table 1 Controlled Velocity Test Program with Whisper 100 Turbine

Test Series	PRIMARY Variables bladedelta = B-# Unit mod in cm B#	V	air speed = V# air speed in m/s #	quasi stead = S gust = G Flow desc S or G	Furl = Fe or Fd enabled/disabled Fe or Fd
B00V05SFe	B0	V	5	S	Fe
B00V10SFe	"	"	10	"	"
B00V15SFe	"	"	15	"	"
B00V20SFe	"	"	20 TBA	"	"
B00V05GFe	B0	V	5	G	Fe
B00V10GFe	"	"	10	"	"
B00V15GFe	"	"	15	"	"
B00V20GFe	"	"	20 TBA	"	"
B05V05SFe	B05	V	5	S	Fe
B05V10SFe	"	"	10	"	"
B05V15SFe	"	"	15	"	"
B05V20SFe	"	"	20 TBA	"	"
B05V05GFe	B05	V	5	G	Fe
B05V10GFe	"	"	10	"	"
B05V15GFe	"	"	15	"	"
B05V20GFe	"	"	20 TBA	"	"
B20V05SFe	B20	V	5	S	Fe
B20V10SFe	"	"	10	"	"
B20V15SFe	"	"	15	"	"
B20V20SFe	"	"	20 TBA	"	"
B20V05GFe	B20	V	5	G	Fe
B20V10GFe	"	"	10	"	"
B20V15GFe	"	"	15	"	"
B20V20GFe	"	"	20 TBA	"	"
B00V15SFd	B00	V	15 TBA	S	Fd
B00V15GFd	"	"	15 TBA	G	"
B05V15SFd	B05	"	15 TBA	S	Fd
B05V15GFd	"	"	15 TBA	G	"
B20V15SFd	B20	"	15 TBA	S	Fd
B20V15GFd	"	"	15 TBA	G	"

After securing the equipment for road travel the test vehicle with trailer in tow will head to the test site. Cautionary pylons and signage will be placed at either end of the extent of the trial road strip, though it is intended that the work will not impair regular usage of the highway and these markers will be on the road shoulder. A convenient pull-over and turning location will be selected as the preparation station and setting of the equipment for the first run will be undertaken. With all equipment secured and checked for safety and integrity the DA system will be prepped and triggered allowing the commencement of the test.

The first test will be carefully observed by two spotters allowing for immediate suspension of the test by notifying the driver of any apparent problem. Following this test run the vehicle will be returned to the starting position and the equipment reset for the first data experiment. Work is to continue in this fashion until the full matrix of experiments are complete. For closure it is intended to re-test under the same control conditions as the first test of the day, allowing the capture of any unforeseen or uncontrollable drift. Allowing for 10 minutes for each speed test, 30 minutes for blade changes and same for other machine modifications it is anticipated that 6 hours will be required and with room for some repairs and additional tests of field conceived scenarios, a minimum of one full day will be required for the field testing barring catastrophic damage or failure of either the DA system, structural supports, turbine, trailer or test vehicle. Assuming a contingency of one of these setbacks suggests that a second field test window two weeks or more following the first should be planned as a matter of course. The option to cancel it, or use it to conduct new tests after viewing the results of the first, exists.

Note that during the field testing the order of the tests may be changed to increase productivity. The changing of the blades may prove to be the most inconvenient of the test controls, and therefore a full suite of tests for each blade set, including the disabling of furling may be carried out prior to moving on to the next. It is proposed that furling will be disabled by using two standard pipe clamps or tie-wraps placed around the nacelle body fore and aft of the pivot. Gust simulation is to be carried out by fitting a rope through a pulley so that a human hand at one end of the rope (in the truck) may dislodge a loose knot around a blade tip at the other. The slack to pulled in quickly to avoid flapping etc though placement of the pulley will be such that the rope will discharge to the rear of the turbine position. Speed control will be carried through an approximate vector analysis of the wind speed and direction in combination with the road direction and required vehicle speed to obtain the desired range of airspeeds for the turbine. The driver will accelerate and maintain the desired steady road speed at the instruction of the spotter.

At the conclusion of testing a copy of the primary data tape is to be made prior to detailed data investigation. The trailer with mounted equipment is to be left intact in storage until it has been determined that all the experiments for the season have been executed.

To be determined from the video record are all ambient atmospheric data such as air density, barometric pressure, temperature etc, start up wind speeds, furl angular displacement, velocity and acceleration; air speed and its variations at both anemometer locations, and turbine output/performance. Machine output will be measured in terms of instantaneous power, voltage and amps, plus simultaneous rotor RPM. Loads to the turbine nacelle and tower may only be inferred from the observed rate of impact, vibrations sounds or other salient observations.

IV. Results and Analysis

A. *Execution of tests*

At the time of this publication the experimental equipment had been assembled, the test platform constructed and preliminary road testing of the turbine and anemometers had been carried out. These tests were highly successful and confidence-inspiring in so far as the equipment was stable at all road speeds during transport and test simulations. The primary experiments are set to take place over the next month during an acceptable weather window.

It is the intention of the authors to produce plots depicting all trends as may be determined experimentally from the test series indicated in Table 1. Of particular importance will be the graph indicating start-up and power as a function of wind speed for three or more blade geometries, with and without furling allowed. It is hoped that this result will illuminate the sensitivity of power output and nacelle body stresses to blade length under typical and high wind speed operating conditions. In this way a protocol for determining the optimal blade length and multi-unit installation capacity may be developed. It is further anticipated that such a protocol may be put to full scale field trials at select site(s) where experience with existing units offers a control condition. Ultimately, the objective is to increase value through reduced downtime and maintenance as may be achieved by optimally sacrificing efficiency for robustness.

References

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[4] Davis, D., Hansen, C. , Results of the Whisper 900 Testing in Spanish Fork, Utah. DOT, NREL/NWTC workshop July 14-15, 2000